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RE-DESIGN OF ARL/HLF BODY NOSE REGION

G. C. Lauchle & S. J. Giner

Technical Memorandum
File No. TN 84-169
5 November 1984
Contract N00024-79-C-6043

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

One of the experimental objectives for the ARL/Heated Laminar Flow (HLF) body is to provide for limited (low flow) stagnation point fluid ejection. Because fluid ejection can, in many instances, create laminar instabilities farther downstream, it is important to have a stagnation region geometry that helps minimize the enhancement of these instabilities. This is best achieved by using a geometry that supports a very favorable pressure gradient in the ejection region. Such a geometry has been specified for

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the ARL/HLF body. The important analytical results which led to this re-designed nose region are presented in this report. The results include potential flow pressure distributions, boundary layer development, and disturbance amplification ratios, for both the original and modified nose geometry. In the absence of fluid ejection, it is concluded that the laminar flow performance of the modified body will be the same as that of the original body.

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The ARL (Penn. State Univ.'s Applied Research Lab.) Heated Laminar Flow (HLF) body is a streamlined body with a pointed nose.

From: G. C. Lauchle and S. J. Giner

Subject: Re-Design of ARL/HLF Body Nose Region

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Introduction

The ARL/Heated Laminar Flow (HLF) body is a streamlined body with a pointed nose. Ref. [1] gives the details of its design. Many of the initial experimental objectives for this body have been completed [1]. One of the current objectives requires that fluids of various properties be ejected from the forward stagnation point. The ejector to be used is an orifice of sufficient size to provide a given flow while keeping the efflux velocity less than 5 percent of the free-stream velocity. Reference [2] provides some design guidelines for ejectors on laminar flow bodies, which we are following.

For high-speed operation, the ejector nozzle must be large (on the order of 0.125-inch diameter). The area of this nozzle begins to approach the available stagnation region area of the original heated body design. It was therefore decided to consider replacement of the pointed nose with one having a flat face. The diameter of the flat considered is 0.55 inches. The flat fairs into the original body contour by a 2:1 ellipse. Besides giving more frontal area for a nozzle, the blunter nose would also provide for a very favorable pressure gradient in the ejection region. One would anticipate that this more favorable gradient would help to minimize the de-stabilizing effects that fluid ejection has on downstream laminar stability. A critical trade off with this approach, however, is not to make the gradient so favorable, that pressure recovery is unstable. In order to support the design changes suggested, a series of hydrodynamic calculations were performed for the modified nose design and compared with those for the original design. The results of these calculations are presented in this report. All of these results are in the absence of any fluid ejection.

Calculations Performed

Both viscous and non-viscous external flow calculations were performed. These include the potential flow pressure distribution with tunnel blockage included, boundary layer growth over the heated and unheated body, and laminar boundary layer stability calculations with and without heat addition. For all of the viscous flow calculations, the TAPS code [3] was used. Water temperature was held constant at 75°F. The pressure distributions were computed using the Douglas-Neumann code [4]. For the heated conditions, a heat flux distribution was used as input (as opposed to a temperature profile). The total, integrated heating power (Q_T) for this distribution is 27kW. As can be seen from Fig. 1, this distribution is the lowest one used in previous experimental programs. It was reasoned that any changes, in laminar stability due to the modified nose would be most pronounced for the no heat or minimal heat conditions. Thus, only the results for these two conditions are presented here.

Results

Potential Flow

The computed in-tunnel pressure distributions over the original and modified nose are given in Fig. 2. It is noted that the modified nose can be manufactured by parting off the original nose 0.225 inches aft and then fairing the flat into the original body contour by a 2:1 ellipse. The pressure distribution for the modified nose is clearly more favorable than the original nose design, which is beneficial if stagnation point ejection is to be used. Equally important is the absence of a minimum pressure point in the nose region. The gradient remains favorable from the stagnation point to the maximum diameter point, 8 feet downstream.

Boundary Layer Development

The velocities selected for all viscous flow calculations are 10, 25, 40, and 55 ft./sec. Figures 3 and 4 show the laminar displacement thickness and momentum thickness Reynolds number growth over the heated portion of the forebody. These curves are for both the original and modified nose designs. The differences in boundary layer growth between the two designs are so small that they cannot be detected in plots of these types. Also, the effect of heat on laminar boundary layer development is small, as indicated in Fig. 4(b). We note that all Reynolds numbers shown in these figures are based on free-stream velocity.

Linear Stability of Laminar Boundary Layer

The TAPS code provides solutions to a modified Orr-Sommerfeld equation. These solutions exist for given complex eigenvalues. The real part of the eigenvalues, which are determined by a subroutine of TAPS, represent a critical frequency for laminar instability. The imaginary part represents an amplification rate for a disturbance at the critical frequency. This amplification is expressed as $\ln A = \ln (a/a_o)$, where a_o is the initial disturbance amplitude and a is the disturbance amplitude at a given location downstream of where a_o occurs. The point on the body where $a = a_o$ is defined as the neutral stability point. Usually, ln A must exceed 9 for transition to occur. In presenting results, the eigen-frequencies, ω, are normalized by U_o^2/ν, where U_o is the free-stream velocity and ν is the kinematic viscosity.

Figures 5 through 8 show the linear stability calculation results for both nose designs and with no heat supplied to the body skin. In comparing the original nose results with the modified nose results, it becomes clear that the neutral stability point on the modified nose is slightly farther downstream than it is on the original nose design. This is apparently due to the more favorable pressure gradient on the modified nose. The e^9 locations may also be slightly different, but the differences are so small that we can conclude that the cold body transition locations on the modified body should remain at basically the same points they were on the original body.

Figures 9 through 11 show the linear stability results computed using the heat distribution discussed previously (Q_T = 27kW, Figure 1). This particular distribution was determined as the one necessary to keep all local displacement thickness Reynolds numbers less than or equal to a specified minimum critical Reynolds number for a flow velocity of 10 ft./sec. [5]. Certainly that has been verified here since the TAPS calculations have yielded zero amplification for the 10 ft./sec. condition (hence, a figure is not shown for 10ft./sec.). Figures 9 and 10 suggest that transition will not occur on the heated forebody for $U_o \leq 40$ ft./sec. At 55 ft./sec., Figure 11 suggests that the transition point would be in the vicinity of 2.25 feet for both nose designs. It can be concluded from these figures that the modification to the nose region will have little or no effect on the heated performance of the HLF body.

Conclusions

The hydrodynamic calculations described in this report are appropriate to assess whether a slight modification to the nose region of the ARL/HLF body would result in degraded laminar flow performance. We conclude that this modification will not degrade such said performance.

The modification has been found to shift the neutral stability point slightly farther downstream. This fact suggests that the modified nose should be a better design than the original design if fluid ejection or some other potentially destabilizing feature is added to the most forward regions of the subject body. It is realized that further calculations with and without fluid ejection would add support to these conclusions, but the computational tools required for such a study are not currently operational. The use of ejection fluids of properties different from those of water also complicates the development of these tools.

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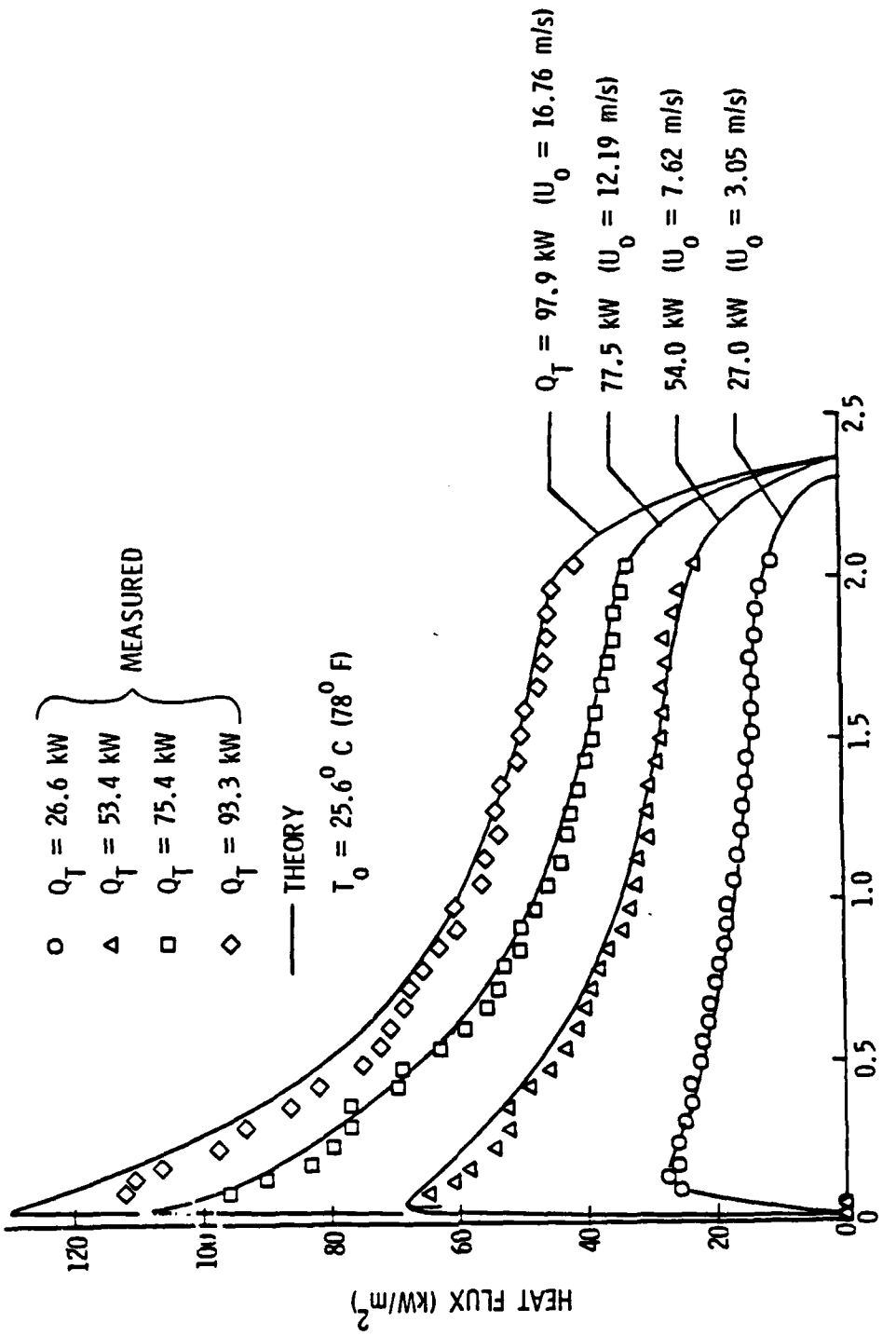


Figure 1. Heat Flux Distributions used on the ARL/HLP Body.

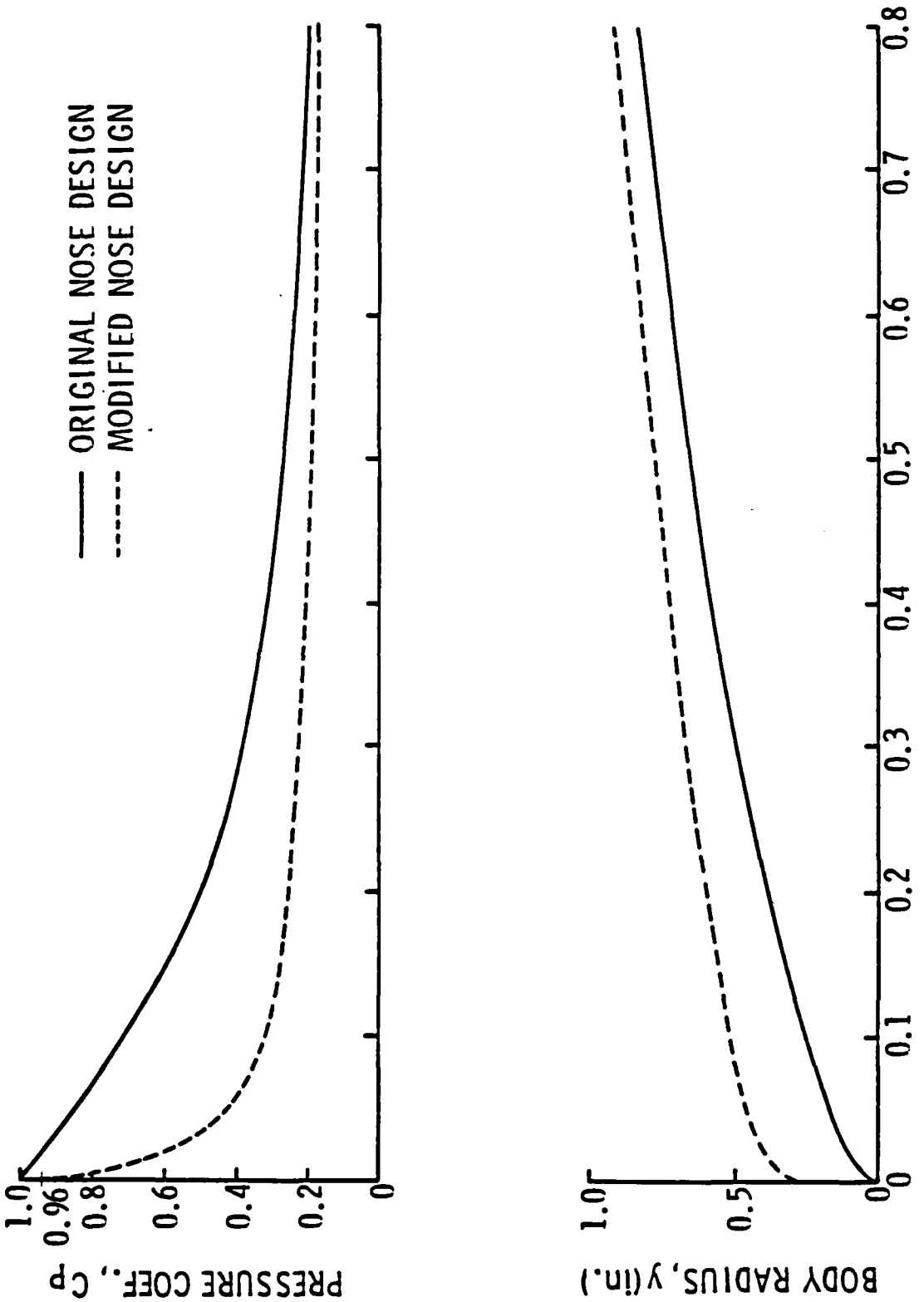
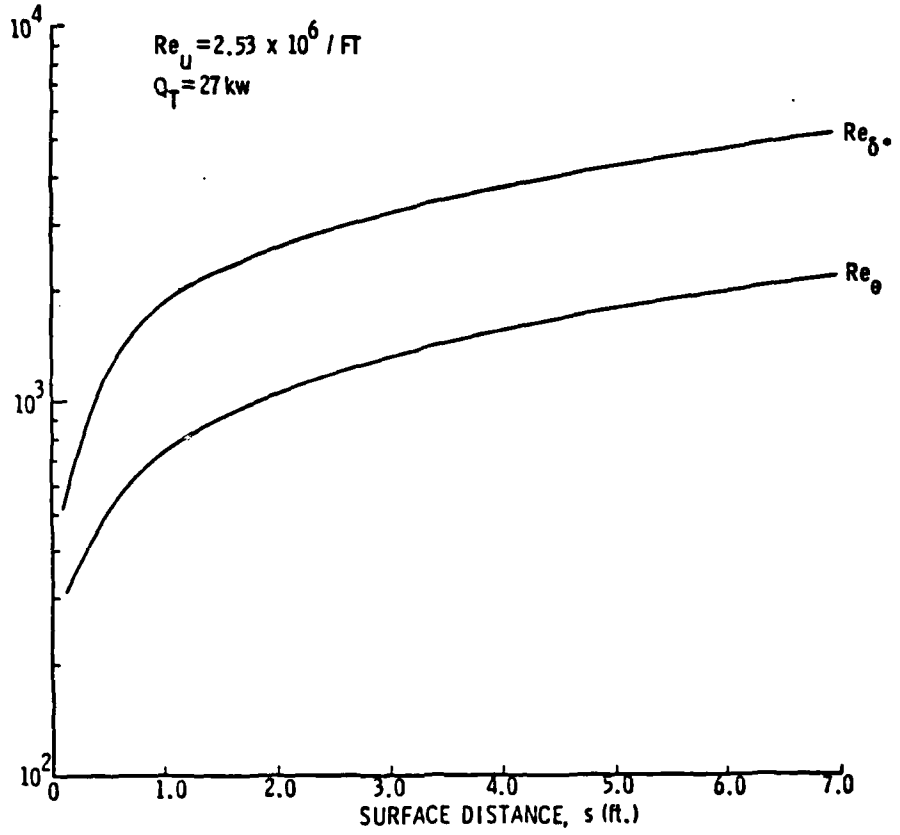


Figure 2. Potential Flow Pressure Distributions on the Original and Modified Nose Geometries.



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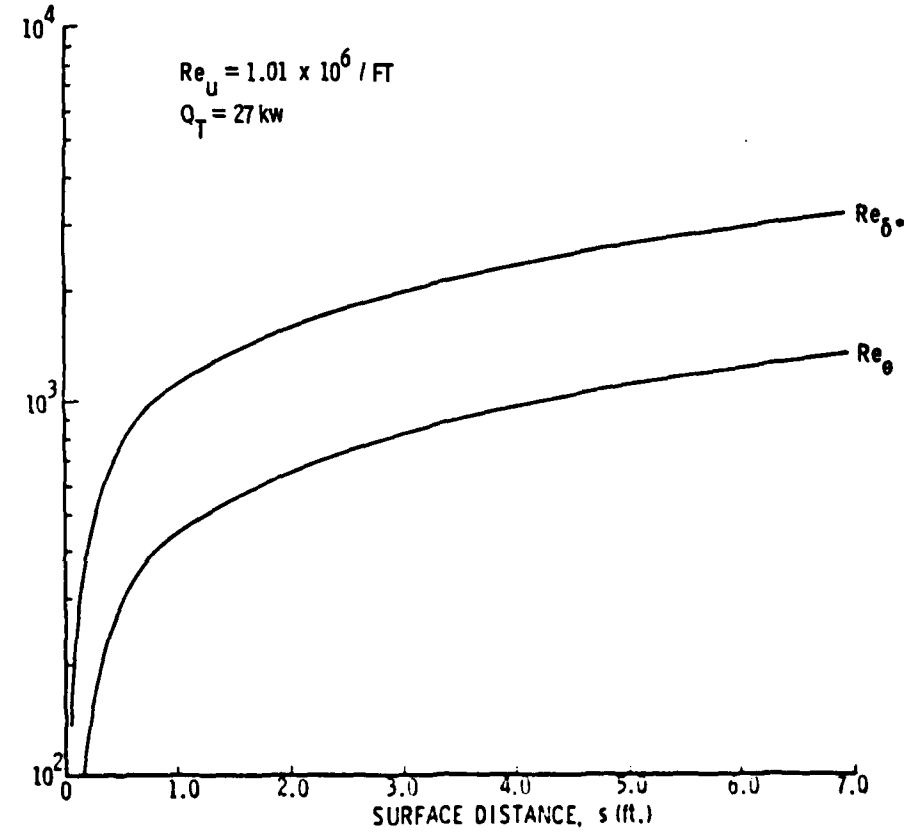
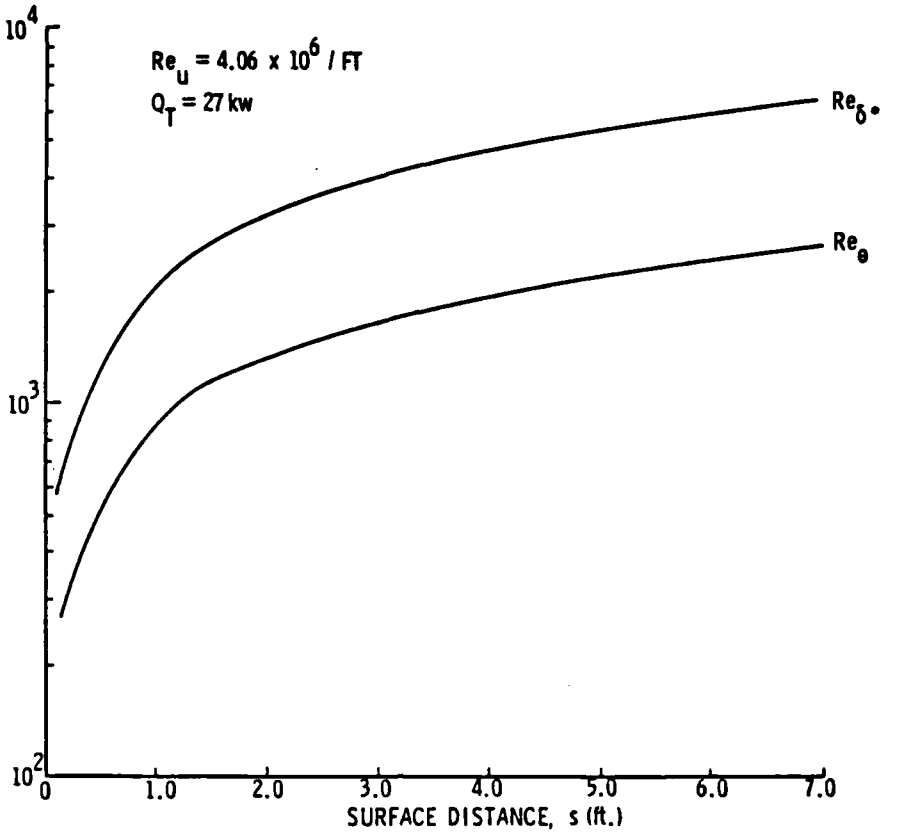


(b)

Figure 3. Laminar Boundary Growth over either Original or Modified ARL/ELF Body: (a) 25 ft./sec.; (b) 10 ft./sec.



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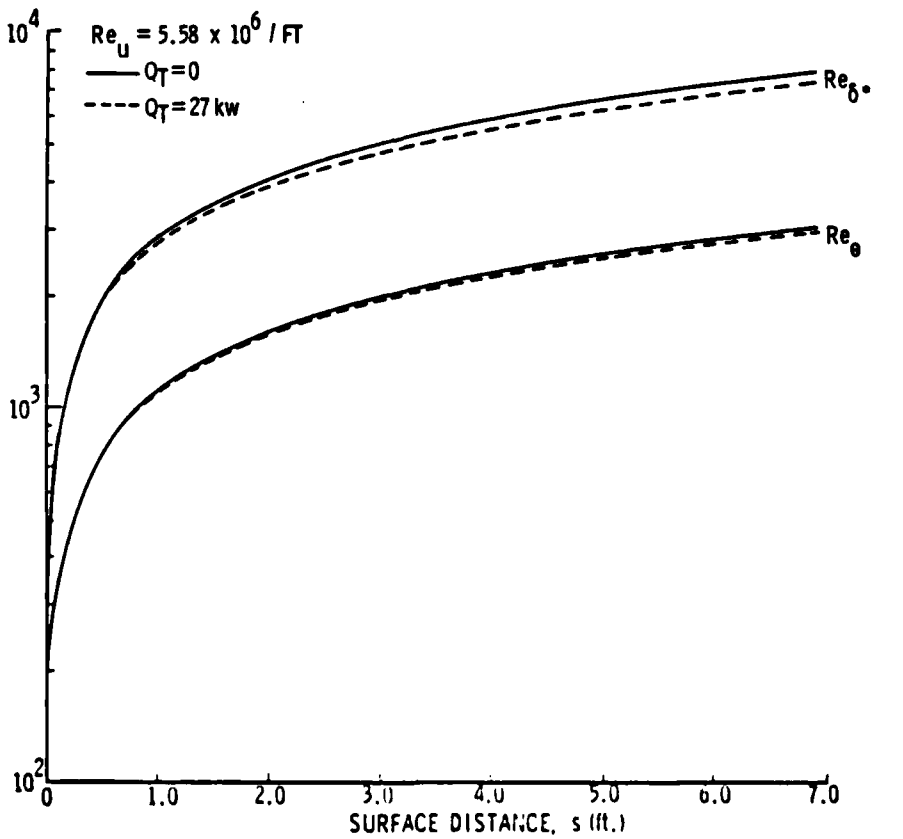
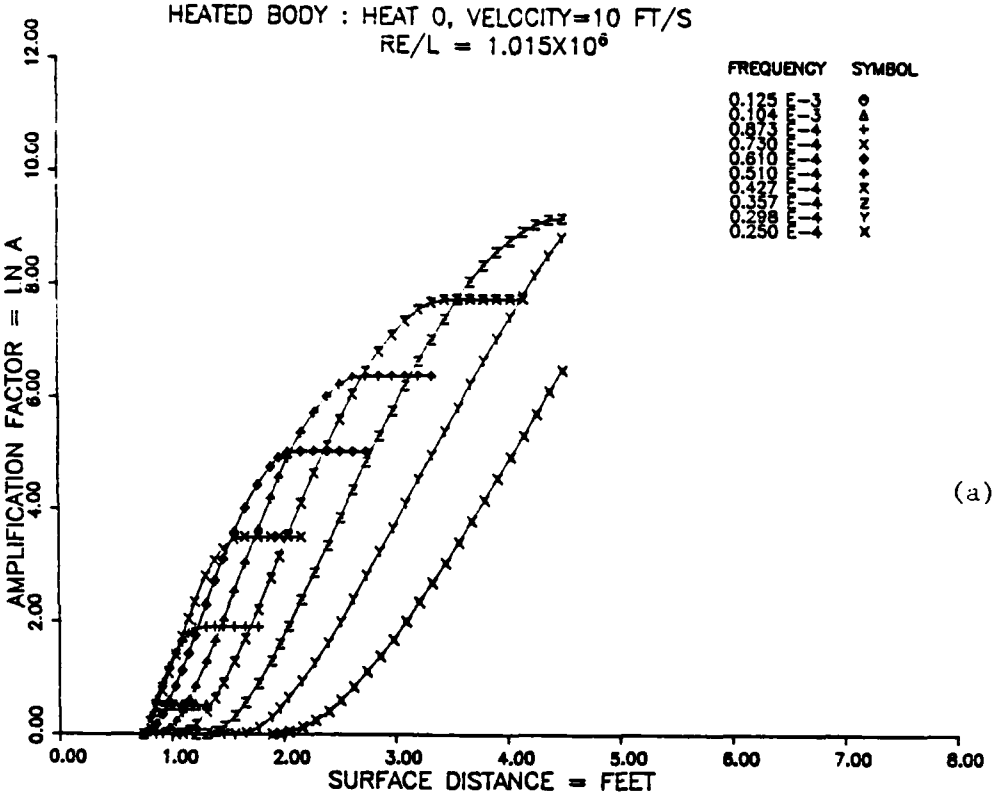


(b)

Figure 4. Laminar Boundary Layer Growth over either Original or Modified ARL/HLF Body: (a) 40 ft./sec.; (b) 55 ft./sec.



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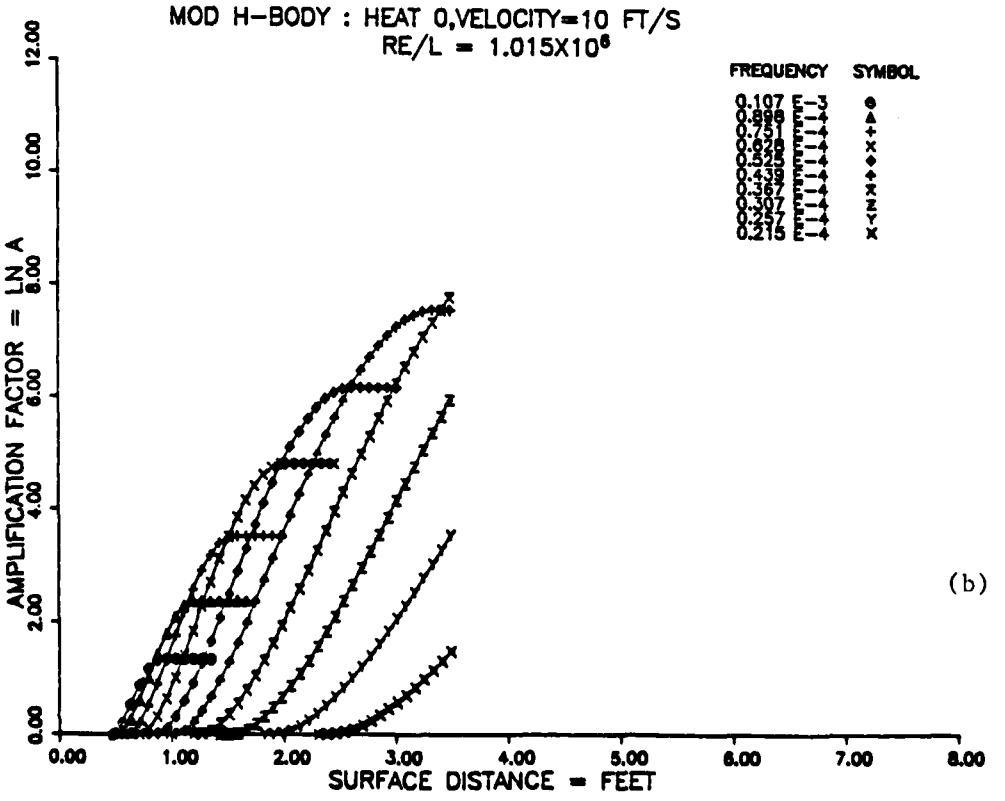
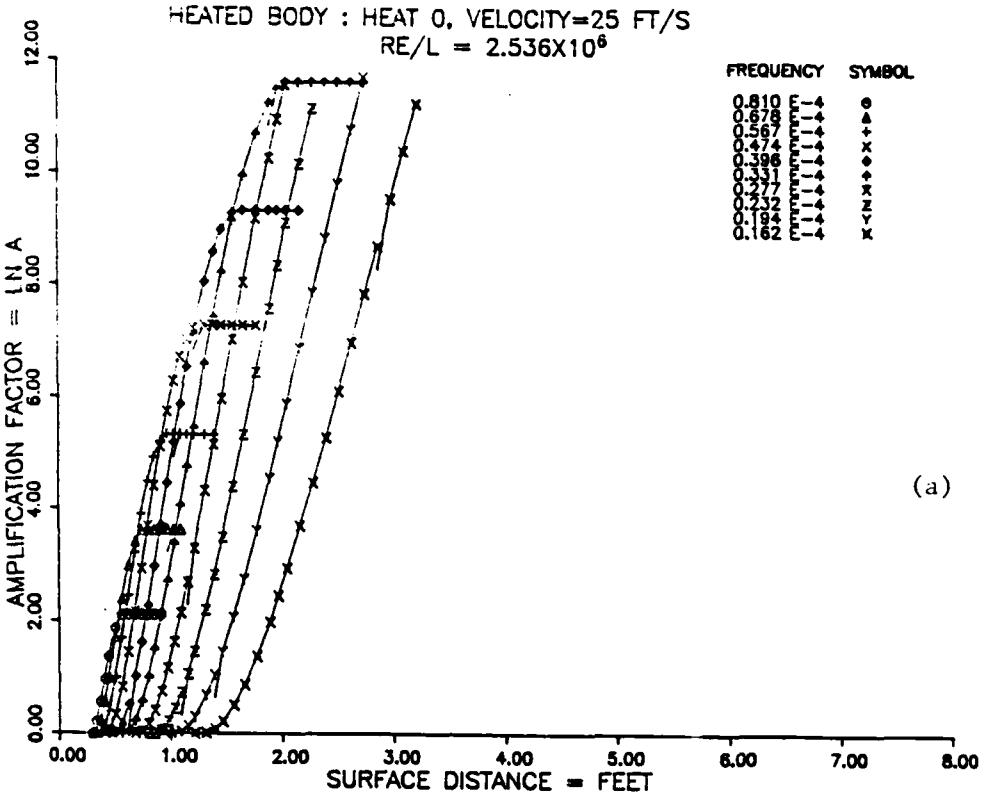


(b)

Figure 5. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with no Heat and at 10 ft./sec.



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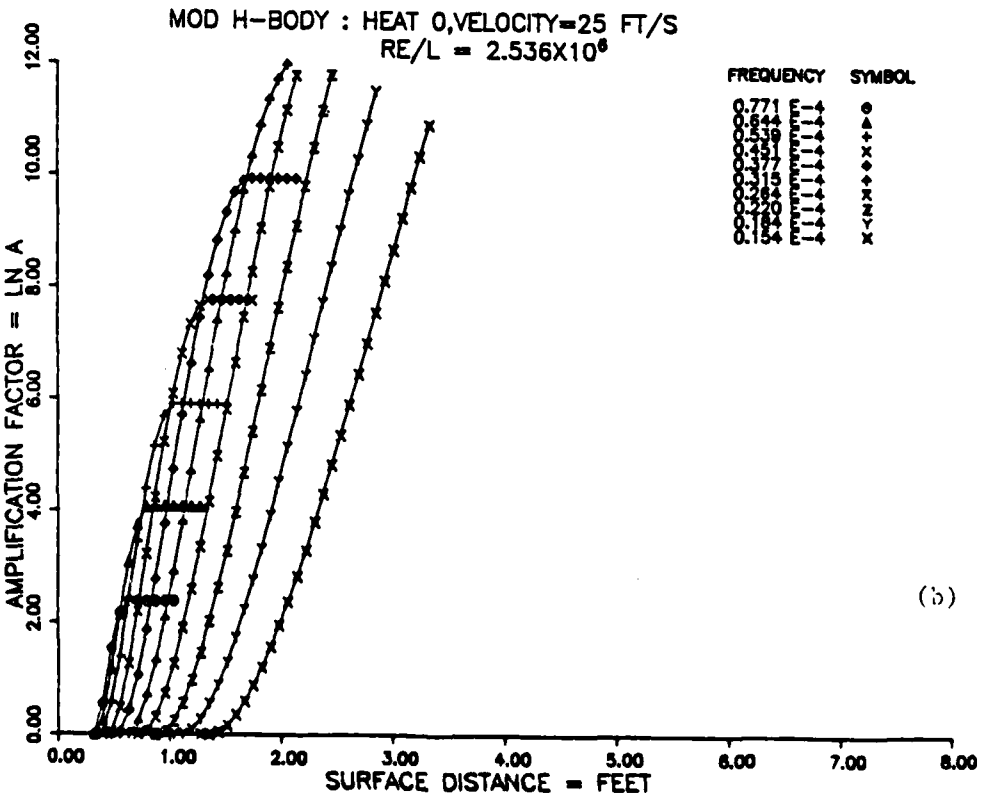
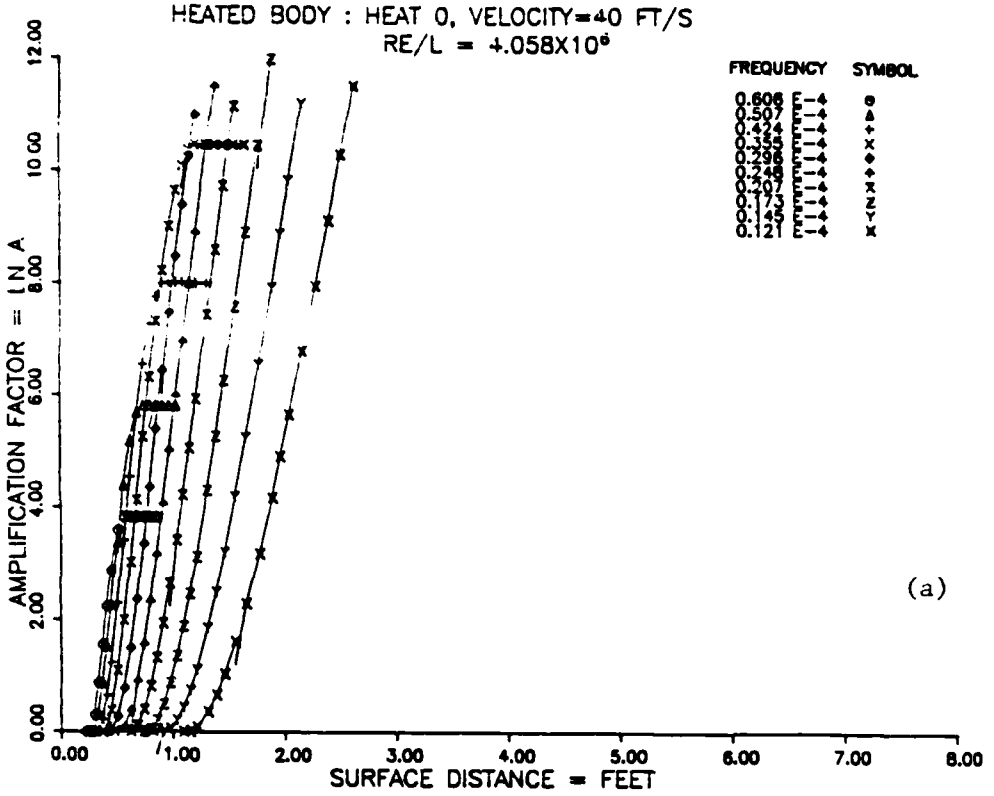


(b)

Figure 6. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with no Heat and at 25 ft./sec.



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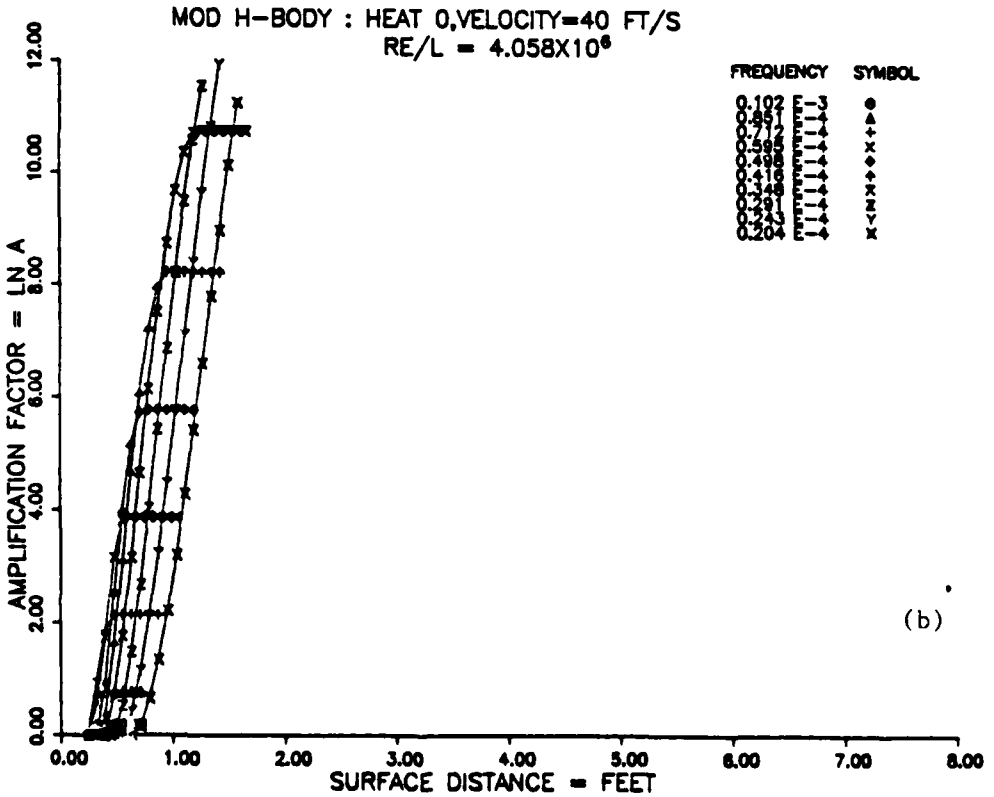
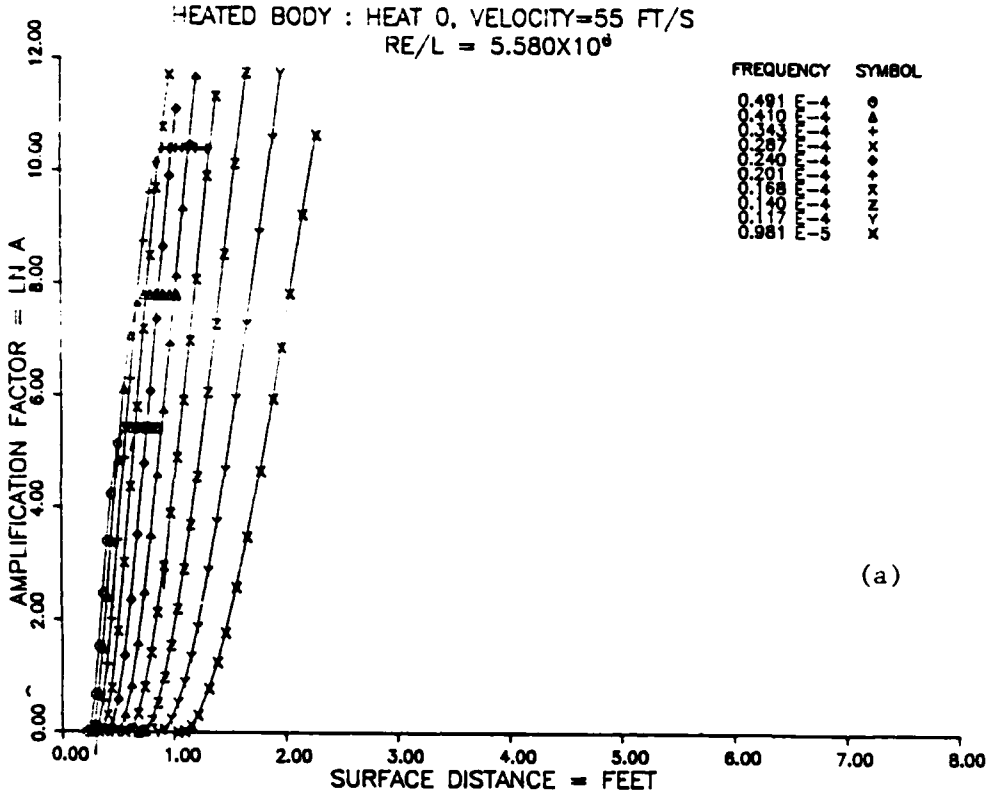


(b)

Figure 7. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with no Heat and at 40 ft./sec.



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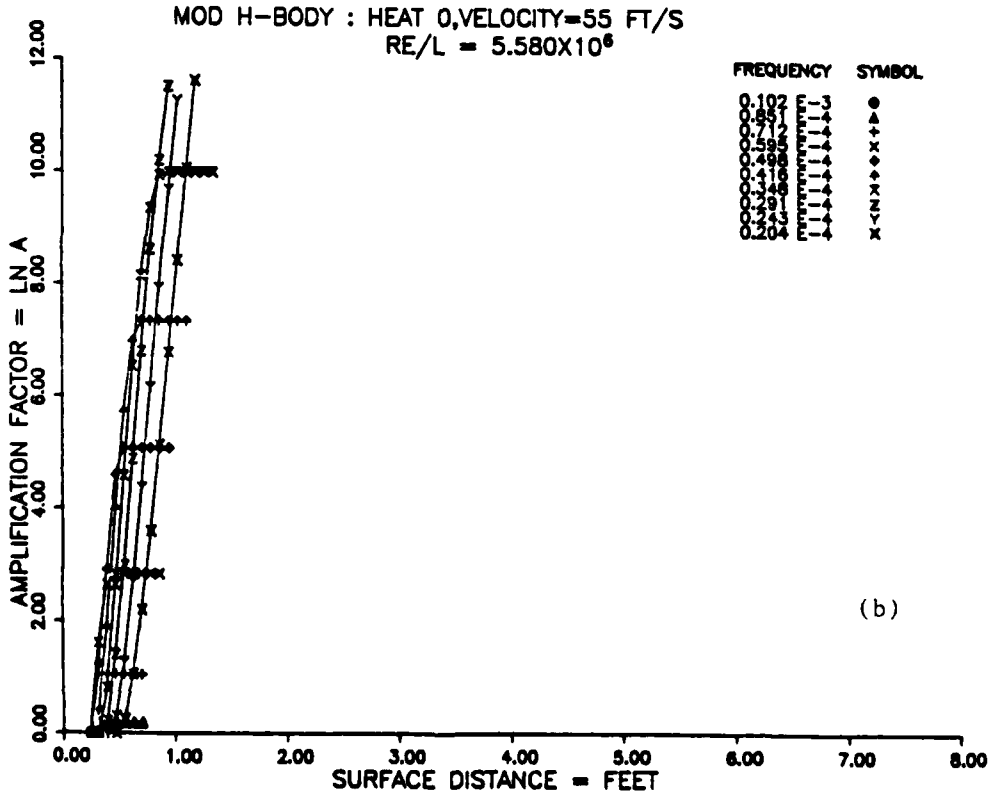
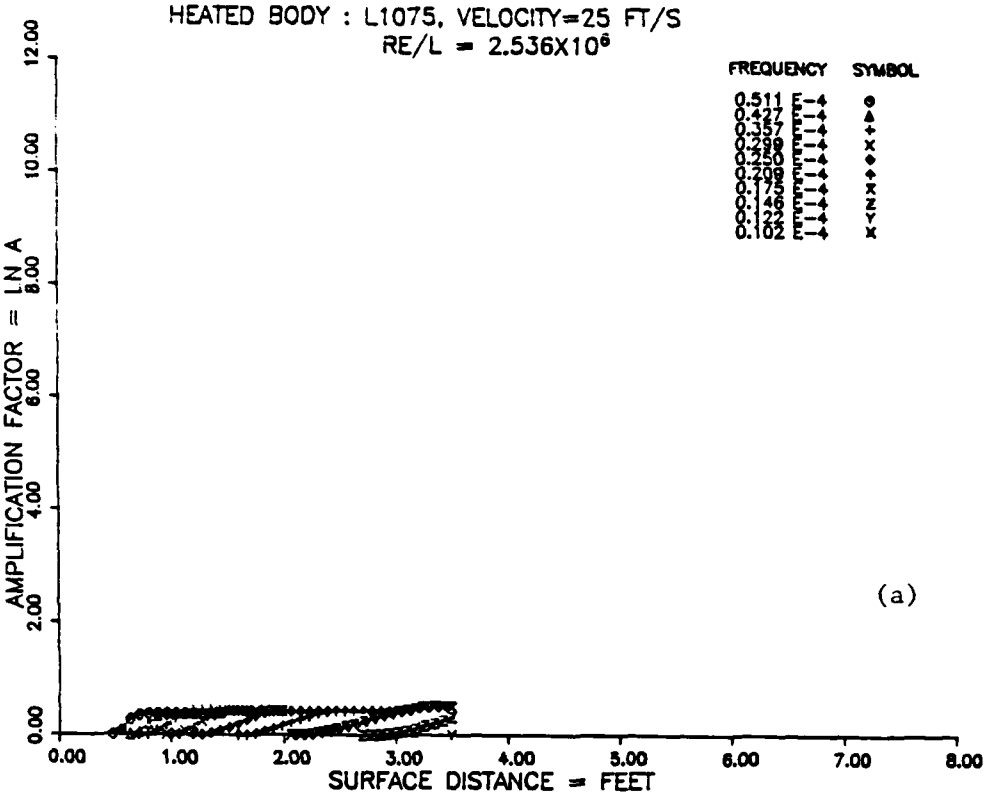


(b)

Figure 8. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with no Heat and at 55 ft./sec.



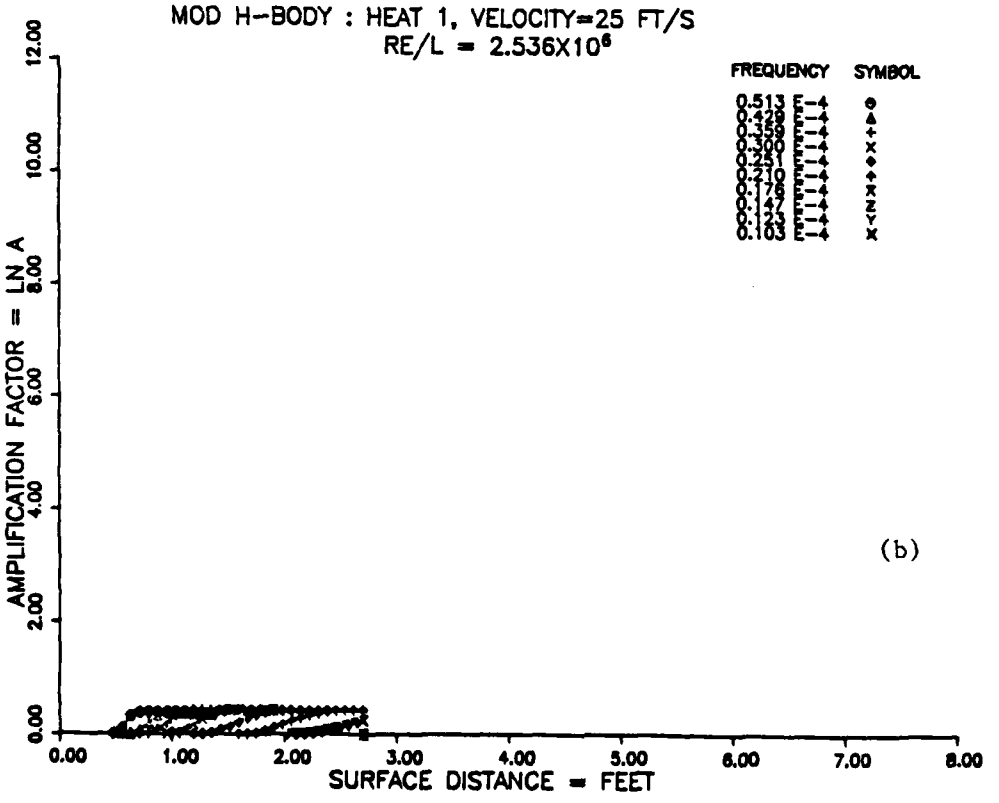
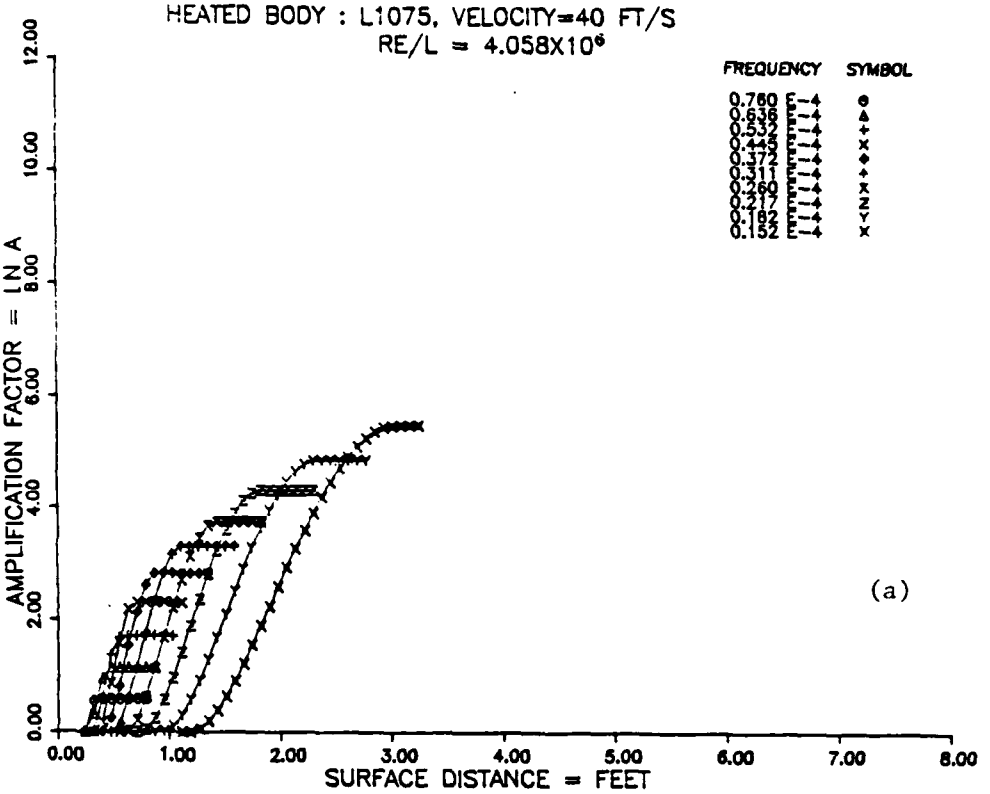


Figure 9. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with Total Heat Q_T = 27 kW and at 25 ft./sec.



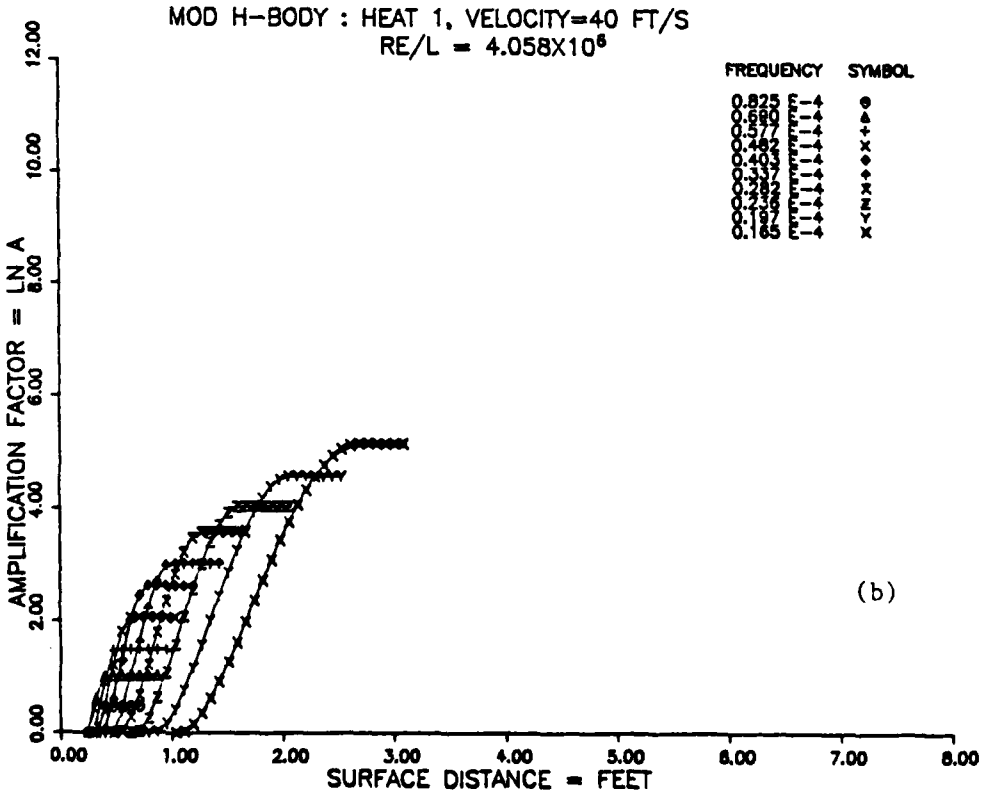
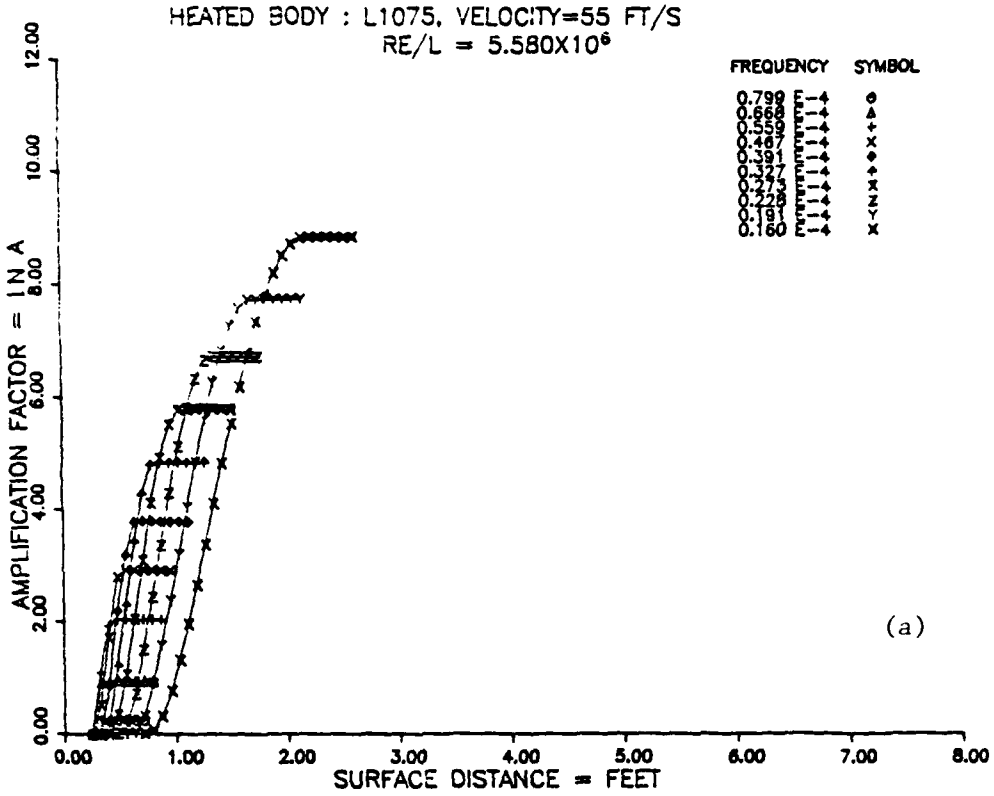


Figure 10. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with Total Heat Q_T = 27 kW and at 40 ft./sec.



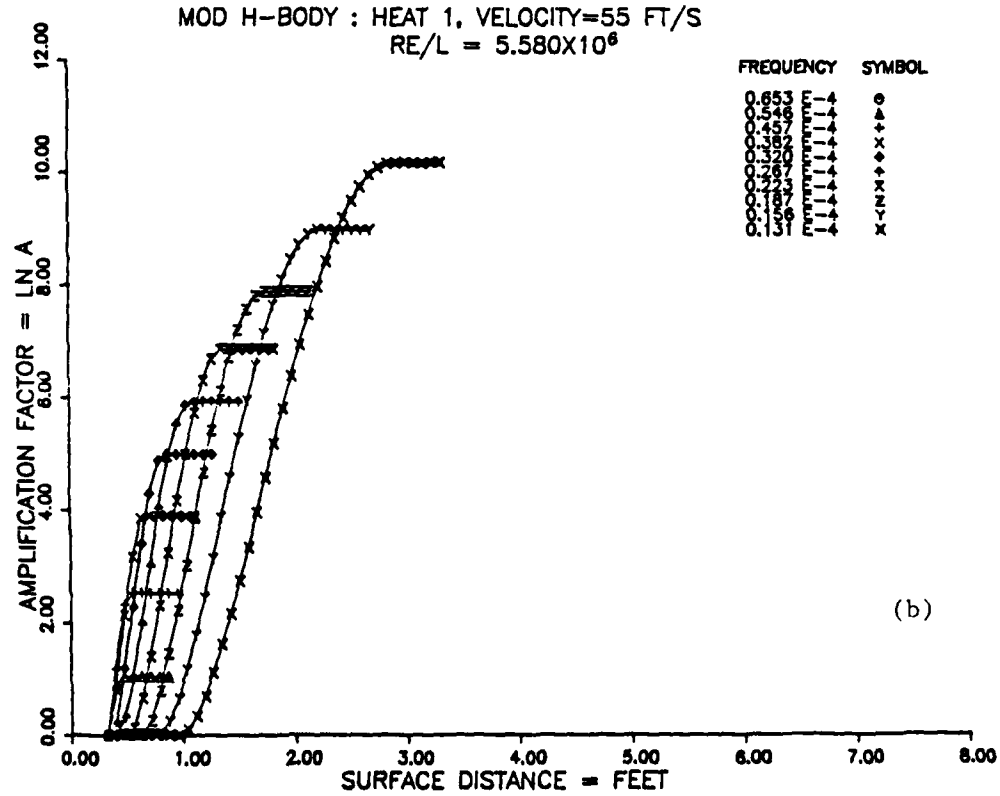


Figure 11. Linear Stability Curves for (a) Original and (b) Modified ARL/HLF Body with Total Heat Q_T = 27 kW and at 55 ft./sec.

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